

# Microlithographic Reduction Projection Catadioptric Objective

Cross-References to Related Applications - Not applicable.

Statement Regarding Federally Sponsored Research or Development - Not applicable.

Reference to a Microfiche Appendix - Not applicable.

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## Background of the Invention

### Technical Field

The invention concerns a microlithographic reduction projection catadioptric objective comprising an even number greater than two of curved mirrors, being devoid of planar folding mirrors and featuring an unobscured aperture.

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### Background Art

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Such objectives are known from European Patent document EP 0 779 528 A (Fig. 3) as variants of pure catoptric objectives, with six mirrors and three lenses. All optical surfaces are symmetric to a common axis and an object plane and an image plane are situated on this axis upstream and downstream of the objective. However, all but one of the mirrors need to be cut off sections of bodies of revolution, so that mounting and adjustment face difficulties. The lenses serve only as correcting elements of minor effect. The most imageward mirror is concave.

US Patent 4,701,035 (Fig. 12) shows a similar objective. This one, however, has nine mirrors, two lenses and two intermediate images. The object plane and image plane are situated within the envelope of the objective.

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In both cases the image field is an off-axis ring sector.

A fully axially symmetric catadioptric objective is known from German Patent document DE 196 39 586 A (corresponding to US Patent Application Serial No. 09/263,788), e. g., with

two opposing concave mirrors, an image field centered at the axis, and a central obscuration of the aperture.

Another type of catadioptric objective suitable for microlithographic reduction projection has only one concave mirror, but at least one folding mirror, and is known from US Patent 5,052,763 and European Patent document EP 0 869 383A inter alia and is referenced here as "h-design".

US Patent 5,323,263 discloses a microlithographic reduction projection catadioptric objective with multiple folding mirrors, where an intermediate image is arranged subsequent to a first concave mirror and a singly passed lens group.

US Patent 5,575,207 and US Patent 4,685,777 show very similar multiply folded catadioptric objectives.

#### Summary of the Invention

It is an object of the invention to provide a generic objective of good capabilities of chromatic correction for typical bandwidths of excimer laser light sources, which allows for a high imageside numerical aperture, and which reduces complexity of mounting and adjusting.

The solution to this problem is found in the present invention.

#### Brief Description of the Drawings

The invention is described in detail with respect to the drawings, wherein:

Fig. 1 shows a front end of an objective;

Fig. 2 shows the lens plan of a version of the objective; and

Fig. 3 shows the lens plan of another version of the objective.

## Detailed Description of Preferred Embodiments

An important concept of the present invention is to replace the front end of an "h-design" objective with a different front end that provides a single axis system.

5 In the simplest version of this new front end, set up to be part of a -0.25 reduction. 0,75 image side NA system with a 7 mm x 26 mm rectangular image field size, the optical elements are shown in the lens section of Fig. 1. This catadioptric partial system provides a virtual image on the right hand side, which has enough axial chromatic aberration to compensate for a conventional focusing lens group that forms a 0.75 NA image. A real pupil or aperture plane is formed on the right hand end of the system. The system shown has enough Petzval sum so that  
10 the focusing lens group can be made up of mostly positive power lenses.

There is only one field lens LI in this system, which is close to the object plane (Ob) end of the system. That location is an advantage with respect to lens heating. There are no aspherics in this front end, and none are needed. The mirrors M1 to M4 are all spherical and coaxial to the common optical axis. It is possible to correct this front end system for spherical aberration of the  
15 pupil, but that requires a somewhat larger concave mirror than shown here. Spherical aberration can as well be corrected in the focusing lens group and therefore the size of the concave mirror M3 is minimized. Decreased size of mirror M3 simplifies the mechanical construction of the system. In the example of Fig. 1, the concave mirror M3 has an illuminated area that is about 165mm wide in the plane of the drawing and about 500 mm in the orthogonal direction, for a 7  
20 mm x 26 mm image field size.

The greatest distance of any ray from the common optical axis is 370 mm in this example. This is substantially less than for many designs of the "h-design" type, where the concave mirror thickness and mount thickness must be added in to the sideways ray path

distance after the fold mirror, from the axis to the concave mirror. The package envelope of this new design is more attractive.

More axial chromatic aberration and Petzval curvature can be introduced by the front end (FE) than in the example of Fig. 1, by increasing the power of the negative lens L2 near the concave mirror M1. A strong lens L2 however, tends to introduce too much overcorrected spherical aberration and makes the intermediate image aberrations too large. Thus, a better version of the design has two concave lenses near the concave mirror.

The field lens LI near the object plane Ob can also be split into two weaker lenses, to help control pupil aberration. Finally, the convex mirror M2 that is near the reticle (Ob) can be split off from the field lens LI surface and made to be a separate optical element. This more complicated design is capable of better performance.

It is possible to make this system meet all of the first-order specifications of a typical microlithographic objective as well as correct for Petzval curvature, and axial and lateral color correction, with only positive lenses in the telecentric focusing group (TFG). An example is shown in Fig.2, without any other kind of aberration correction. The lens heating is substantially uniform, as the beam diameter is large on all the lenses L21 to L29.

Fig. 3 shows a further embodiment example. The front end FE' features a field lens group split into 3 lenses L31 to L33, which helps achieve a good quality telecentricity. Also, the focussing lens group (FLG') now has more lenses L36 to L44. This focussing lens group FLG' has a few aspherics. There are also some aspherics in the catadioptric front end FE' of the design that simplify correction, though they are not compulsory. The large mirror M33 is still a sphere, as this simplifies production.

Preferred locations of the aspheric surface are near an aperture or pupil plane, namely on mirror M31 or on lenses L34, L35, where the marginal ray height exceeds 80% of the height of the neighboring aperture, and on the other hand on some distant locations with marginal ray height less than 80% of the height of the next aperture. Examples of the latter are surfaces of the field lens group or of the last two lenses next to the image plane Im.

The polychromatic r.m.s. wavefront error value in this design now varies from .05 to 0.13 waves over a 26 X 7 mm field at .75 NA in a 4X design.

The catadioptric front end FE' is now somewhat more complicated than in Figs. 1 and 2. The design is both side telecentric and corrected for pupil aberration and distortion. The working distance is 34 mm on the reticle end (Ob) and 12 mm on the wafer end (Im). The system length is about 1200 mm.

The focusing lens group FLG' is almost all positive lenses (except L41), with no strong curves. The very large amount of aberration at the intermediate image is because the two concave lenses L31, L35 next to the concave mirror M31 do not have the optimum bending under this aspect.

Table I provides lens data for this embodiment.

Mechanical construction of the lens barrel for this type of objective is very advantageous when compared with catadioptric systems with folding of the optical axis (as "h-design" etc.). Here, only the mirrors M32 and M33 cannot be full disks. Mirror M33, however, can be extended to a full annular body that can be mounted in a rotationally symmetric structure. The barrel must be cut between the lenses L33 and L36 at a lower side of the drawing of Fig. 3 to provide passage to the light beam, but generally can be cylindrical. Only mirror M33 must be positioned outside this cylindrical barrel, but at a very moderate distance.

With "h-designs", a similar effect needs additional folding. Folding mirrors are generally not desirable, as they cause intensity losses and quality degradation of the light beam, and production costs and adjustment work without benefit to image quality.

It is possible to produce mirror M33 as an annular blank, and it can be mounted as this  
5 annular part in a cylindrical barrel that is extended in diameter in this area.

It can be seen that concave spherical mirror M33 is the only mirror extending outside of a cylindrical envelope scribed around all the lenses that has the radius of the lens of greatest radius. This shows again that this type of objective is suitable for mounting in a compact cylindrical barrel of high intrinsic rigidity.

10 The lens material in the given examples is calcium fluoride, fluorspar. Other materials standing alone or in combinations, may be used, namely at other wavelengths of excimer lasers. Quartz glass, eventually suitably doped, and fluoride crystals are such suitable materials.

Four, six and eight or more mirror objective designs known in the field of EUV lithography are generally suitable as starting designs for the front end group of the invention,  
15 with the eventual deviation that a virtual image instead of a real image is provided.

These embodiments are not intended to limit the scope of the invention. For example, in addition to curved mirrors, planar folding mirrors may occasionally be introduced into the system according to the invention.

All the features of the different claims can be combined in various combinations  
20 according to the invention.

Table 1

CODE V&gt; 115

Shafer-design .75NA,4x.75mm Obj.-hight

	RDY	THI	RHD	GLA	CCY	THC	GLC
> OBJ:	INFINITY	34.000000			100	100	
1:	147.23281	21.000000		'CAF-UV'	100	100	
2:	236.79522	1.000000			100	100	
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	0.273300E-07	B :	0.201130E-11	C :-.871260E-16		D :0.118100E-19	
AC :	100	BC :	100	CC :	100	DC :	100
3:	145.44401	27.000000		'CAF-UV'	100	100	
4:	224.64885	51.185724			100	100	
5:	-223.00016	25.004072		'CAF-UV'	100	100	
6:	-184.59445	162.666291			100	100	
7:	-97.23630	12.000000		'CAF-UV'	100	100	
8:	-928.69926	24.980383			100	100	
9:	-75.28503	15.000000		'CAF-UV'	100	100	
10:	-116.14787	3.000000			100	100	
11:	-134.28262	-3.000000	REFL		100	100	
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	0.474810E-08	B :	0.506570E-12	C :-.284590E-17		D :0.934830E-21	
AC :	100	BC :	100	CC :	100	DC :	100
12:	-116.14787	-15.000000		'CAF-UV'	100	100	
13:	-75.28503	-24.980383			100	100	
14:	-928.69926	-12.000000		'CAF-UV'	100	100	
15:	-97.23630	-162.666291			100	100	
16:	-184.59445	-25.004072		'CAF-UV'	100	100	
17:	-223.00016	-11.195502			100	100	
18:	-363.91714	11.195502	REFL		100	100	
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :-.107960E-07		B :0.170830E-13		C :-.328180E-16		D :0.143630E-20	
AC :	100	BC :	100	CC :	100	DC :	100
19:	-223.00016	25.004072		'CAF-UV'	100	100	
20:	-184.59445	162.666291			100	100	
21:	-96.00000	15.000000			100	100	
ASP:							
K :	-1.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :0.000000E+00		B :0.000000E+00		C :0.000000E+00		D :0.000000E+00	
AC :	100	BC :	100	CC :	100	DC :	100

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Table I (Continued)

CODE V&gt; 11s

Shafer-design .75NA.4x.75mm Obj.-hight

	RDY	THI	RHD	GLA	CCY	THC	GLC
22:	INFINITY		24.980383			100	100
23:	-247.00000		67.808099			100	100
ASP:							
K :	-1.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	0.000000E+00	B :	0.000000E+00	C :	0.000000E+00	D :	0.000000E+00
AC :	100	BC :	100	CC :	100	DC :	100
24:	-237.00000		266.861281			100	100
ASP:							
K :	-1.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	0.000000E+00	B :	0.000000E+00	C :	0.000000E+00	D :	0.000000E+00
AC :	100	BC :	100	CC :	100	DC :	100
25:	-470.62323		-266.861281	REFL		100	100
26:	-210.84570		266.861281	REFL		100	100
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	-.419940E-08	B :	-.904030E-13	C :	-.297400E-17	D :	-.106340E-21
AC :	100	BC :	100	CC :	100	DC :	100
27:	INFINITY		35.031723			100	100
28:	1621.80000		33.000000	'CAF-UV'		100	100
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	0.155580E-07	B :	-.854090E-12	C :	0.123240E-16	D :	-.559700E-21
AC :	100	BC :	100	CC :	100	DC :	100
29:	-747.60113		67.859320			100	100
30:	827.21786		27.000000	'CAF-UV'		100	100
31:	-1939.50000		20.227637			100	100
32:	197.25357		14.999969	'CAF-UV'		100	100
33:	128.31113		39.542169			100	100
34:	-1370.10000		24.000000	'CAF-UV'		100	100
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	-.164770E-07	B :	0.155510E-11	C :	-.542070E-16	D :	0.556740E-20
AC :	100	BC :	100	CC :	100	DC :	100



Table I (Continued)

CODE V&gt; 11s

Shafer-design .75NA.4x.75mm Obj.-hight

	RDY	THI	RHD	GLA	CCY	THC	GLC
35:	-253.41246	18.476467				100	100
36:	109.90063	30.001392		'CAF-UV'		100	100
STO:	242.23740	22.529315				100	100
38:	-264.99438	46.219742		'CAF-UV'		100	100
39:	-372.29467	0.998929				100	100
40:	173.30822	24.000000		'CAF-UV'		100	100
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :	0.628520E-07	B :.	.915530E-11	C :.	.628040E-15	D :.	.946620E-19
AC :	100	BC :	100	CC :	100	DC :	100
41:	1411.60000	4.845900				100	100
42:	110.28842	22.740804		'CAF-UV'		100	100
43:	160.79657	13.371732				100	100
44:	69.10873	45.185600		'CAF-UV'		100	100
45:	-895.78799	11.999039				100	100
ASP:							
K :	0.000000	KC :	100				
IC :	YES	CUF:	0.000000	CCF:	100		
A :.	.113590E-06	B :0.281520E-09		C :.	.171880E-12	D :0.507740E-16	
AC :	100	BC :	100	CC :	100	DC :	100
IMG:	INFINITY	0.000000				100	100
SPECIFICATION DATA							
NAO	-0.18750						
TEL							
DIM	MM						
WL	157.63	157.63	157.63				
REF	2						
WTW	1	1	1				
XOB	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	0.00000	0.00000					
YOB	0.00000	26.51700	40.00000	53.03300	64.95100		
	70.15600	75.00000					
WTF	0.00000	0.00000	1.00000	1.00000	1.00000		
	1.00000	1.00000					
VUX	0.00000	-0.00138	-0.00308	-0.00534	-0.00803		
	-0.00941	-0.01082					
VLX	0.00000	-0.00138	-0.00308	-0.00534	-0.00803		
	-0.00941	-0.01082					
VUY	0.00000	-0.00065	-0.00224	-0.00398	-0.00520		
	-0.00531	-0.00535					
VLY	0.00000	-0.00370	-0.00706	-0.01156	-0.01709		
	-0.01985	-0.02220					

